INVESTIGATION OF LASER DYNAMICS, MODULATION AND CONTROL BY MEANS OF INTRA-CAVITY TIME VARYING PERTURBATION

under the direction of

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INTRODUCTION

The work under this Grant is generally concerned with the generation, control, and stabilization of optical frequency radiation. Previous work under this Grant has been largely concerned with the control of normally multimode lasers by means of internal time varying perturbation. The work in this area is now nearly complete, and will be described briefly below. The more recent and upcoming work under this Grant is concerned with the generation of light by means of parametric processes in nonlinear media. The present projects under this category include a combined theoretical and experimental study of optical parametric oscillation wherein the nonlinear element is placed internally to the cavity of the pumping laser; and a second project whose goal is the parametric generation of light without the need for multiple optical cavities. In the following sections we will review the status of each of the above projects.

During this period the following publications have been submitted for publication, or published, and are included as Appendices:

S. E. Harris, "Threshold of Multimode Parametric Oscillators," published in IEEE J. Quant. Electr., October 1966, p. 701.

L. M. Osterink and R. Targ, "Single Frequency Light from an Argon FM Laser," submitted to Appl. Phys. Letters.

S. E. Harris, "Stabilization and Modulation of Laser Oscillators by Internal Time-Varying Perturbation," published in Proc. IEEE and Appl. Optics, October 1966, p. 1639.

The following oral disclosure has also been presented:

S. E. Harris, "Temporal Modulation of Light," Optical Society of America Meeting, San Francisco, October 1966.

PRESENT STATUS

1. FM Oscillation in the Argon Laser and Single Frequency Techniques

(L. Osterink and S. E. Harris)

During this period the experimental work on the argon FM laser has been completed. In a joint experiment with R. Targ of Sylvania Electronic Systems, a single frequency output power of 350 mW of single frequency light at 5145 Å has been obtained. The distortion, or total residual power in all side bands, was less than 0.2% of the total power. Several continuous hours of single frequency output were achieved with only occasional minor adjustment of the external modulator drive.

Particular emphasis has been devoted to studying the effect of power dependent homogeneous broadening on the distortion in the FM laser. It was experimentally determined that as the power of an argon laser is increased, with the modulator drive remaining fixed, the distortion of the FM oscillation is actually reduced. In effect, the homogeneous broadening tends to reduce the difference between the net saturated gain and loss of each mode of the coupled oscillation, and thereby reduces the total distortion. Extrapolation of this result indicates that as the power of the argon laser is further increased, increasingly less modulator drive will be required, thereby easing the problem of modulator construction. The result also indicates that in some very homogeneous laser lines, for instance YAG, negligible modulator drive may be required to achieve excellent FM oscillation.

As noted above, the experimental work on this project is now complete. During the coming period computer and analytical work will be completed and a paper published.

We note that the present work on this phase of the Grant is closely coordinated with the supermode work at the Sylvania Advanced Technology Laboratory, which is supported there under NASA Contract NAS-8-50558, funded from Huntsville, Alabama.

2. Parametric Oscillation at Optical Frequencies

(M. K. Oshman, R. Byer, C. Someda, and S. E. Harris)

The purpose of this project is to study, both experimentally and theoretically, parametric generation at optical frequencies. The initial emphasis of this project has been directed toward an investigation of the dynamics of an optical parametric oscillator wherein the nonlinear material is situated internally to the cavity of the pumping laser.

The principle results of the initial theoretical study of such an oscillator pointed out the following:

(i) The internal parametric oscillator is capable of very efficient operation,

(ii) the strong pump fields existing inside the laser cavity are useful in overcoming the required threshold for oscillation, and

(iii) the oscillator can exhibit three distinct modes of operation.

During the interval since the last report, the emphasis of the work on this project has been directed toward the experimental aspects of constructing such an oscillator. This work consists of design and performance calculations followed by experimental construction and testing of the elements necessary for the oscillator.

In the design calculations, essentially all available lasers and nonlinear materials were considered. The results of this investigation led to the decision to use $LiNbO_3$ as the nonlinear crystal due to its high nonlinearity and usefulness in the visible and near infrared regions of the spectrum. As the pump laser, the relatively high power ionized gas lasers were chosen.

An rf pumped ring discharge configuration was chosen as the design for the ion laser. A 10 MHz oscillator capable of delivering approximately 10 kilowatts of power to the laser on a continuous basis was constructed. Several laser tubes have been constructed and tested with both argon and krypton gas as the laser material. With argon, the laser is capable of producing a cw output power in each strong line of approximately one watt; with krypton, one-quarter watt.

In order to substantially increase the gain of the laser to the point that the insertion of the nonlinear crystal will not significantly lower the laser pump power, a second laser tube is being built to run in series with the first tube. The second tube will have an independent rf pumping source.

A great deal of effort has been directed toward testing a fabrication of $LiNbO_3$ crystals for use as the nonlinear element of the oscillator. Very high optical quality crystals with very flat anti-reflection coated ends are necessary to prevent degradation of the Q of the optical cavity for signal, idler, and pump. There are a number of problems associated with this requirement, all of which have been either overcome or should soon be solved.

The general optical quality of the crystals available from outside suppliers is apparently below acceptable levels for usefulness with internal optical parametric oscillators. For example, the bulk scattering and absorption of crystals 2 cm long was on the order of 5% at 1.15 μ. We believe this problem will be solved with improved crystal growing procedures which have been developed at Stanford. In addition, $LiNbO_3$ exhibits inhomogeneities developed by the pumping laser light itself. To solve this problem a stable oven has been constructed which maintains the crystal at a sufficiently high temperature to reverse the development of the inhomogeneities at a rate greater than they are formed. In conjunction with this portion of the work, techniques for phase matching at these elevated temperatures were developed.

The surface properties of the $LiNbO_3$ must be extremely good for the crystal to be useful inside a resonator. Successful procedures have been developed for obtaining very flat, scratch-free surfaces. In addition, a technique which includes both Brewster angle cutting and anti-reflection coating has been designed so that reflections can be reduced at all three frequencies of the oscillator.

3. Backward Wave Oscillation in the Far Infrared*

(C. Wilkinson, J. Murray, C. Someda, J. Falk, and S. E. Harris)

The purpose of this project is to demonstrate a technique for obtaining large amounts of far I-R power, readily tunable over the range of 100 to 1000 μ. The basic idea is to make use of a backward wave

*The work on this project was partially supported by Contract AF 19(638)-1429.

interaction of three electromagnetic waves which are coupled by means of the electro-optic nonlinearity. Of particular importance is the fact that in a backward wave oscillation, feedback is provided internally to the nonlinear process, and therefore optical cavities for the signal and idler modes are not required. The technique also provides a means for continuously off-setting the frequency of a pump laser by about 10 Å.

The proposed experiment makes use of a Q-switched ruby laser and a nonlinear crystal of $LiTaO_3$. The far I-R (lowest frequency wave) is taken as the backward wave, and the three waves involved satisfy the $\bar{k}$ matching condition, $\bar{k}_s + \bar{k}_i = \bar{k}_p$. As a result of this $\bar{k}$ vector matching, the signal frequency is related to the pump frequency by the relation

$$\frac{\nu_s}{\nu_p} = \frac{\eta_i - \eta_p}{\eta_i + \eta_s} \qquad (1)$$

where η_i , η_p , and η_s are the refractive indices at the pump, signal, and idler frequencies, respectively. By controling the temperature of the crystal over a range of about 100 degrees, the signal frequency should be tunable from 100 to 1000 μ.

The calculated threshold pump power density for this process is 135 MW/cm^2 for a crystal 1 cm in length, and varies inversely as (length)^2. Assuming the existence of a diffraction limited laser, optimum focusing considerations yield a pump spot area of about 0.02 cm^2 for a crystal 1 cm in length, and therefore a required pump power of about 3 MW. Our laser is, however, very far from being diffraction limited, and the effect of this divergence is not yet understood.

Progress on this project during this quarter has included:

(1) De-bugging and stabilization of the high power Q-switched ruby laser. The laser now furnishes between 60 to 80 MW in a single longitudinal mode having a beam divergence of about $5\ 10^{-3}$ radians.

(2) The construction of a Dewar system for possible operation at liquid helium temperatures.

(3) The measurement of birefringence as a function of temperature in $LiTaO_3$.

At present, work on this project is being badly hampered by our inability to obtain a properly poled crystal of $LiTaO_3$. Such crystals are, however, available at other laboratories and most likely will be obtained during the coming quarter.

APPENDICES

A. S. E. Harris, "Threshold of Multimode Parametric Oscillators," Microwave Laboratory Report No. 1458, published IEEE J. Quant. Electr. QE-2, 701 (October 1966).

B. L. M. Osterink and R. Targ, "Single Frequency Light from an Argon FM Laser," Microwave Laboratory Report No. 1484, submitted to Appl. Phys. Letters.

C. S. E. Harris, "Stabilization and Modulation of Laser Oscillators by Internal Time-Varying Perturbations," Microwave Laboratory Report No. 1429, published in Appl. Optics 5, 1639-51 (October 1966).